Refractory parctices in electric arc and induction furnaces

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Introduction

With the introduction of ladle metallurgy and continuous casting, the EAF is being utilised basically for melting down the charges with minimum refining time. A number of developments have taken place with regard to the EAF technology in order to increase productivity, thermal efficiency and to reduce cost of production of steel. It has been noticed that there is an increase of steel production through EAF process and in the year 1993, the world steel production through EAF process was around 31.0%. Some of the developments taken place in EAF steel technology are as follows :

- High power/long arc operation
- Water cooled shell and roof panels
- Foamy slag practice
- Scrap pre-heating
- Introduction of oxy-fuel burners
- Bottom tapping
- Inert gas purging
- Introduction of DC-Arc furnace

Many of these developments and renovations have become possible only because of simultaneous development of refractories used in EAF. Some of the newly developed refractories are magnesia-carbon, alumina, silicon carbide, carbon bricks and precast shapes, magnesia-carbon purging elements, dry basic ramming masses, precast high alumina mixes for DC-Arc furnace etc. In this paper, the different refractories used in EAF and Induction Furnaces have been discussed in details.

Design and Refractory lining practices of AC Furnaces

Side wall area

The side wall is generally lined with pitch/resin bonded magnesia-carbon refractories with a residual carbon content of 5-20%. Pitch bonding instead of resin bonding will be favoured more and more at the moment due to price/performance ratio.

In the hot spots, the area of most severe wear high grade pitch or resin bonded magnesia-carbon bricks with 10-20% residual carbon are giving satisfactory performance. Metal-cased MgO-C bricks are also used for stability reason. Slag zone of EAF is lined with MgO-C bricks with 10-20% residual carbon. This magnesia-carbon bricks are generally made based on higher crystal size sintered magnesia or fused magnesia. The product selection is made in order to get the balanced wear out profile in different parts of the side wall.

Roof lining

The delta section of EAF roofs with water cooling panels are lined either with burned bauxite based bricks or with precast blocks made of high alumina castables. Electrodes ring are lined with burned bauxite base bricks. If high alumina castables are used for the lining of the roof on the site, a sufficient drying facilities is necessary. Installation of precast block is advantageous. This precast blocks are generally made of 70-90% Alumina low cement castable and has the advantages of easy installation, high installation efficiency and immediate use without drying. The life of precast blocks is approximately 2-3 times higher compared with the conventional one.

In case of roofs without water cooling panels either high alumina or burned magnesia-chrome bricks are used in the delta section as well as in the outer part.

Hearth

A number of chemical, thermal and mechanical factors continuously act upon the hearth. So, refractories to be used in the hearth should have the following characteristics :

- Resistance to steel and slag infiltration
- Higher erosion and scrap impact resistance
- Resistance to fluctuation of tempeature

The hearth is generally lined with wet magnesia ramming mass. Recently, conventional wet magnesia ramming mass has been replaced with dry ramming mass as the later offers a number of advantages over the former one. Some of the advantages of the use of dry ramming mass are mentioned below :

- Simple installation technique
- Short installation time
- No preheating is required
- Lower energy cost and high furnace utilization

This dry magnesite ramming mixes are made with selected grade of magnesia sinter.

Installation technique

At first, material is put in a steel bucket and then taken to the furnace bottom with the help of a crane as shown in Fig-1. It is then distributed evenly on the safety lining which mostly consists of 3-4 flat coarses of fired magnesite bricks and deaired by spiking with shovels. Then, the mass has to be finally compacted with the help of vibro-rammer. Any shape of banks can be formed with the dry ramming mass. A suitable former will be required for shaping the banks when the inclination of the banks exceeds 30 Degree. The newly rammes hearth can be put into operation immediately after the ramming is completed. But it is recommended to cover the hearth and banks with thin steel sheets to prevent the damage of hearth by impact of first bucket of scrap charged into the furnace. Table-1 shows the properties of ramming mixes used.

Tap hole area

Generally, there are two systems of tapping in EAF - Conventional side tapping, and the bottom tapping system.

A. Conventional side tapping

Pre-fabricated blocks are generally used in case of side tapping system. The advantages of using pre-fabricated blocks are -

(i) Lower installation time

(ii) Higher life

These pre-fabricated blocks are generally made with magnesia-carbon quality in high capacity press. Sometimes, a steel pipe is inserted in tap hole and rammed with chemically bonded magnesite ramming mixes. The refractories used in the EAF launder is also varying from plant to plant. Recycled material, cheap repair mixes are generally used. Now-a-days, precast launder made of Al_2O_3-SiC-C castable is gaining importance

B. Bottom tapping system

There are three important bottom tapping system and these are :

- EBT system (Eccentric bottom tapping)

- CBT system (Concentric bottom tapping)
- OBT system (Off-centre bottom tapping)

EBT and OBT systems are widely used because of the following advantages

- Slag free taping —> Decrease of inclusion in steel
- Short tapping time —> Decrease of electric power consumption
- Expansion of water cooled area —> Decrease of refractory cost.

Different refractories used in EBT-EAF and EBT tap hole are shown in Fig 2& 3. Besides, the common short sleeves combination as illustrated in Fig.3. monoblock type has also been developed in Japan. Monoblock type has advantages in brick working and durability. But, the price is high, because they are moulded by cold ISO-static Press. Therefore, the short sleeve combination types are more widely used. Table-2 & 3 show the properties of EBT filling mass and bricks used in EAF.

Maintenance and repair

Hearths installed with ramming mixes as well as with bricks are repaired with dolomite and magnesite fettling materials. Basically, the same mixes can also be used for the repair as well as new installation. But, generally, coarser dust free fettling mixes are preferred for maintenance.

The slag zone as well as the area above the slag zone are gunned with basic gunning material. The consumption of gunning mixes has come down remarkably, because of the introduction of water cooled panels in the side wall, the foamy slag practice and higher distance between electrode and side wall in VHP furnaces.

Development of bottom purging in EAF

Inert gas is purged through purging element placed at the bottom of EAF which gives the following advantages :

- Reduction in tap to tap time
- Homogenization of chemical composition and temperature
- Rapid dissolution of ferro-alloys
- Reduced energy consumption because of improved heat transfer between scrap and steel bath
- Possibilities for improved de-phosphorization and de-sulphurization
- Improved possibilities of de-slagging practices

Two of bottom stirring systems are in operation :

a) Direct stirring system, where the gas is directly blown through the stirring plugs into the steel bath, e.g. by means of multihole plugs.

b) Covered stirring system, where the stirring plugs or tuyeres are covered with a layer of permeable hearth ramming-mix, through which the gas penetrates into the steel bath

DC-arc furnace

DC-arc furnace is becoming increasingly important in the field of electric steel making. A typical DC arc furnace has one centrally positioned graphite electrode from which the DC-arc spans to the steel (Scrap, steel bath). The current flows through the metal and is conducted through the furnace bottom which, therefore, must be conductive.

The conventional EAF is an efficient melting unit. Despite all improvements already made in VHP, AC- EAF has three draw backs. Firstly, side wall deterioration. Secondly, it absorbs substantial losses of thermal efficiency, lastly, it uses consumable electrodes, which accounts for nearly 10% of energy cost. A number of plants in the world are commercially producing steel through DC arc furnace and the benefits of DC arc furnace are mentioned below :

- Less environmental problems, less flicker, low noise,
- Low specific consumption of electrodes, electric power, refractories etc.
- Easy automation

In DC arc furnace, electrically conductive bottom is the key item and it can be achieved either by conductive refractories or by metallic elements as shown in Fig.4

Conductive refractories

In case of conductive refractories, bottom electrodes consist of a large circular copper plate, resisting directly on the air-cooled bottom shell. The copper plate covers around the same area as the melt at the slag line and is provided with connections to water cooled power cables. The conductive refractory hearth consists of safety lining, working lining and protective coating layer. The conductive refractories must fulfill the following requirements while it will be used in the bottom :

(i) Low electrical resistivity 10-3 - 10-4 Ohm-m)
(ii) Uniform resistance
(iii)Low temperature dependence of resistance

(iv) Low thermal conductivity

(v) High stability against thermo-chemical and thermo-physical wear factors to give high service life and a low rate of specific consumption

High quality magnesia-carbon bricks meet these requirements. With graphite as a brick component and a bonding matrix consisting of carbon, they have a high electrical conductivity. With increasing graphite content, electrical conductivity increases, but, unfortunately also so does the thermal conductivity. Therefore, graphite addition must be kept within certain limited. Magnesia-carbon bricks of about 10-12% residual carbon are submitted to a special thermal treatment which lowers the resistance to the required level and eliminates its temperature dependence. Although, the pyrolysis would also occur in an ordinary magnesia-carbon brick during the first few heats in the furnace, thermal pre-treatment offers important advantages for the safe application in a DC-EAF bottom. Firstly, the furnace can be started cold without any preheating, since the electrical resistance of the bottom is low from the very first start-up of operation. Secondly, the low resistance is guaranteed in whole bottom lining i.e. not only in the hot working lining, but also in the safety lining where the temperature is not high enough for complete pyrolysis. Third advantage is the uniformity and homogeneity of the conductivity. Any irregular conductance results in concentration the current density which exceed the normal level of 5000-8000 A/M^2 by many times. Local overheating, hot spots, and a premature wear are the consequence. This risk can only be avoided by a well controlled pre-treatment. It is reported that a life of 4000 heats have been achieved with this kind of bottom design. Table-4 shows the properties of conductive refractories.

In case of non-conductive refractories metallic elements are required. There are various designs like multiple pins, steel fins and wear cooled rods.

Water cooled Rods

One or several billet electrodes are introduced at the furnace bottom and conduct the DC current. The diameter of these steel billets are generally 250 mm. The number depends on the capacity of the furnace (generally 1-4 billet electrodes). The upper section of the billet is in contact with the melt. The billets are embedded into the bottom refractory and water cooled at the external end. Inside the furnace the billets are surrounded with basic refractory bricks. The rest of the furance is lined with a special dry magnesia ramming mix.

Multiple pins

This system uses a large number of round steel bars (about 150-200 pins) which penetrate the refractory down to the bottom shell of the furnace. The pins are between

25.0 mm to 50.0 mm in diameter. The contact pins are attached to the round electric conductor plate and air cooled. Dry magnesia ramming mass is used for complete lining including the areas between the pings.

Specific consumption of refractory materials in EAF

The specific refractory consumption in old fashsioned EAF without water cooling panels and bottom tapping systems is in the range of 12.0 kg per ton of steel. In modern furnaces with water cooling panels and bottom tapping systems it is in the range of 5-6 kg per ton of steel.

Refractories for induction furnace

Induction furnaces are mainly used for melting and holding of metals. There are two types of induction furnaces, the "Coreless" or "Crucible type" and the "Channel type". For melting of cast iron and steel (including alloy steel), present trend is to use coreless induction furnace. The channel type furnaces are mainly used for melting non-ferrous metals and alloys. The lining of coreless induction furnaces in the iron and steel foundries is mostly done with dry ramming masses based on silica. However, in special cases where operating temperatures are very high. i.e., 1700^{0}C or more where special alloy steels with high manganese, nickel and chromium are processed, basic dry ramming masses are used. The basic materials are either magnesite or mag-chrome or magnesia-alumina type. Sometimes, high alumina dry ramming mass is also prefered where mixed quality of steels are made. The properties of different types of materials used in induction furnaces are shown in Table -5.

Conclusion

A number of technological developments have taken place in EAF steel making. Diffeent types of sophisticated refractories like magnesia-carbon, basic dry ramming mass, basic gunning materials, precast shapes based on LCC and ULCC etc., have been developed in order to meet these requirements. Indian Refractory Makers are now producing all kinds of refractories for EAF, but still it has to develop conductive refractories for DC-EAF, purging element etc. The requirement of refractories of induction furnaces are generally met by indigenous sources. A close co-operation is essentially required between refractory makers and users in order to develop high performing cost effective refractories.

Reference

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Table - 1
Properties of basic ramming mixes

	Wet Ramming Mass			Dry Ramming Mass
	(I)	(II)	(III)	
%MgO (min)	84 ± 1	90 ± 1	95 ± 1	85.0
$\%SiO_2$ (max)	-	4.5	2.5	5.0
$\%Fe_2O_3$ (max)	-	-	-	6.0
Grading in mm	(0-5)	(0-2) or (0-5) or	(0-2) or (0-5) or (0-10)	(0-8)
Setting	Chemical	Chemical	Chemical	Ceramic
Sintering temp	1500°C	1550°C	1550°C	1200°C

Table - 2
Properties of EBT filling mass

		EBT Filling Mass
%MgO (min)	:	90.0
$\%Fe_2O_3$ (max)	:	2.0
$\%SiO_2$ (max)	:	2.5
Grading (in mm)		(0-5)
Setting	:	Ceramic

Table - 3
Properties of bricks used in EAF
Al_2O_3-SiC-C BLOCK (TYPICAL VALUES)

% Al_2O_3	75.0
%Fixed Carbon	13.0
%SiC	9.0
%A.P. (by vol.)	9.1
B.D. (gm/cc)	2.98
CCS (kg./Cm^2)	588
Hot MOR at 1400°C (kg/Cm^2)	147
<u>Magnesia-Carbon</u>	
%MgO (in DBM used)(min)	97.0
%Fixed Carbon (min)	10.0
%A.P. (by Vol.) max.	8.0
B.D. (gm/cc)	2.90
CCS (kg./Cm^2)	400
Hot MOR at 1400°C (kg/cm^2)	70
<u>Magnesite</u>	
%MgO (min)	96.0
% SiO_2 (max)	1.0
% Fe_2O_3 (max)	0.5
%A.P. (by vol)	18.0
CCS (kg/cm^2)	500
RUL (ta°C)	1700°C

Table - 5

Properties of induction furnace ramming mass

Silica	
$\%SiO_2$	98.0
Grading (in mm)	(0-5)
Sintering temp. ^0C	1200^0C
Application temp. ^0C	1650^0C
Spinel Type	Mag-Chrome
$\%MgO$ (min)	70.0
$\%Cr_2O_3$(min.)	8.0
Grading (in mm)	(0-5)
Sintering temp. ^0C	$800\text{-}850^0C$
Application temp. ^0C	1750^0C
	Mag-Alumina
$\%MgO$ (min)	70.0
$\%Al_2O_3$	15.0
Grading (in mm)	(0-5)
Sintering temp. ^0C	$800\text{-}850^0C$
Application temp. ^0C	1750^0C

Table - 4

Properties of conductive refractories for DC EAF

Magnesia

Chemical Analysis	
$\%MgO$	97.0
$\%Fe_2O_3$	0.3
$\%Al_2O_3$	0.2
$\%CaO$	2.0
$\%SiO_2$	0.5
%Residual Carbon	10.0
Physical Properties	
%A.P. (by Vol.)	< 2.0
B.D. (gm/cc)	3.05
CCS(N/mm^2)	> 45.0
After ASTM Coking	
%A.P. (by vol.)	< 9.0
B.D. (gm/cc)	3.01
CCS(N/mm^2)	> 40.0
Resistivity after coking	2×10^{-4} Ohm-m

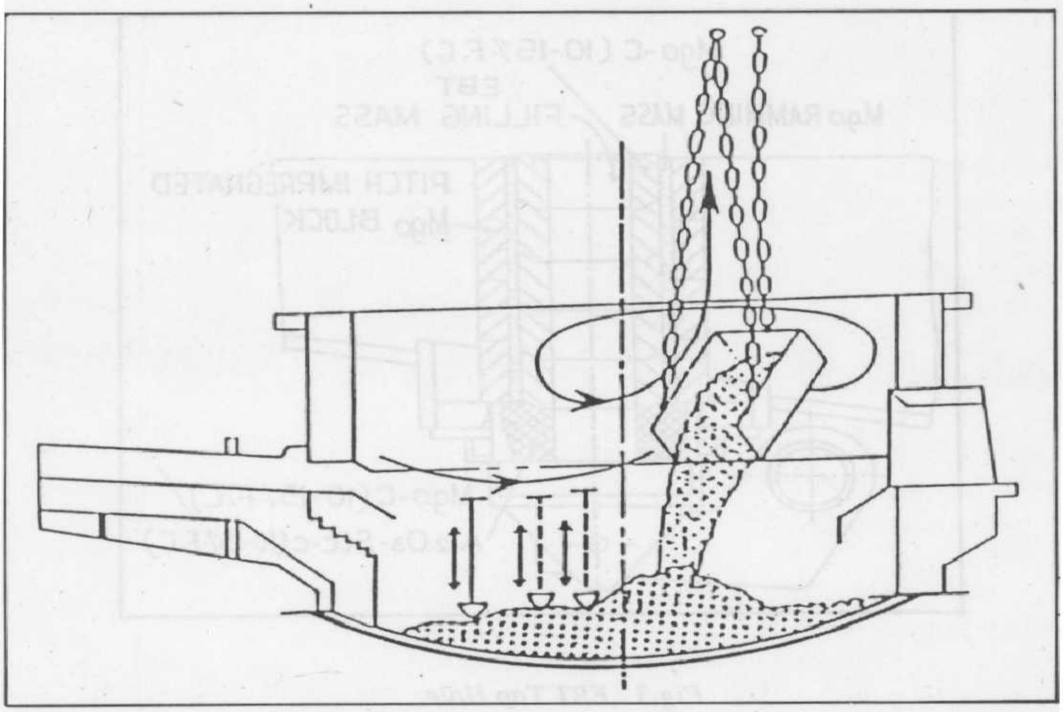

Fig.1 : Installation of dry ramming mass

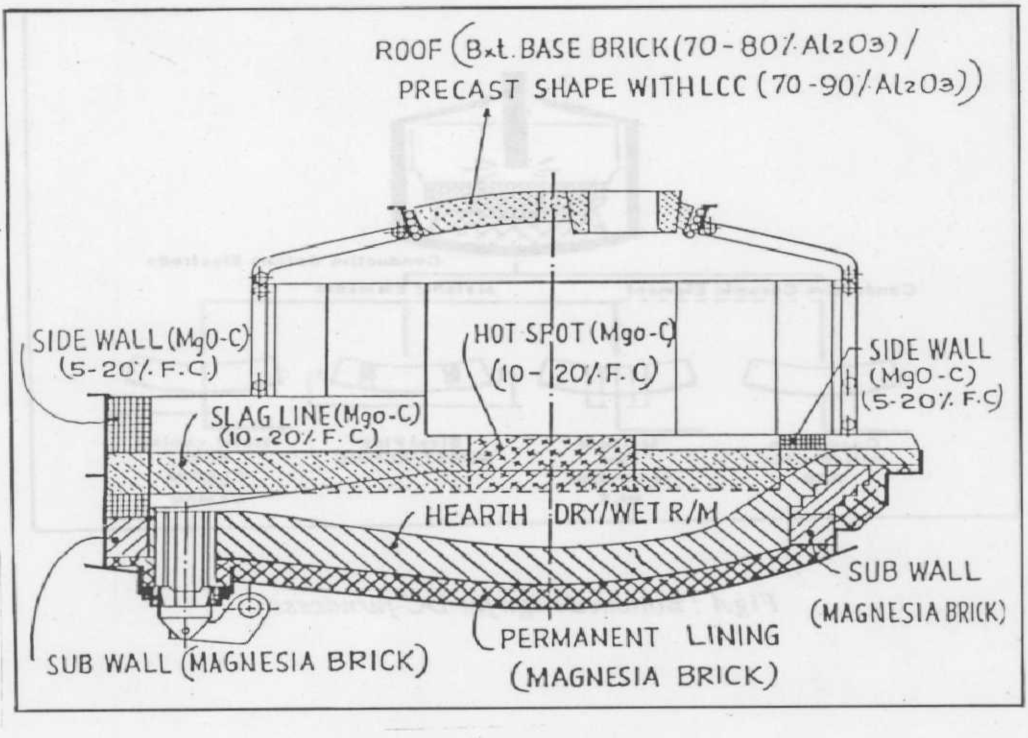

Fig.2 : EBT - EAF

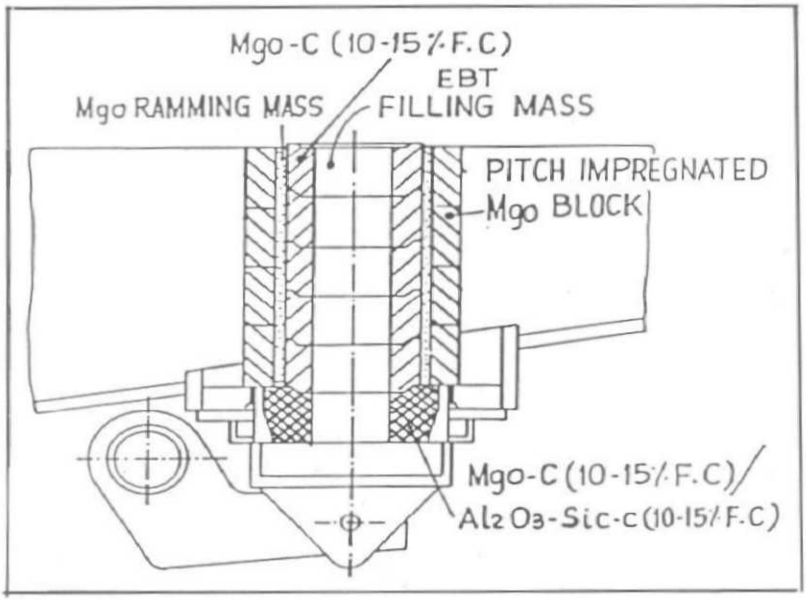

Fig.3 : EBT Tap Hole

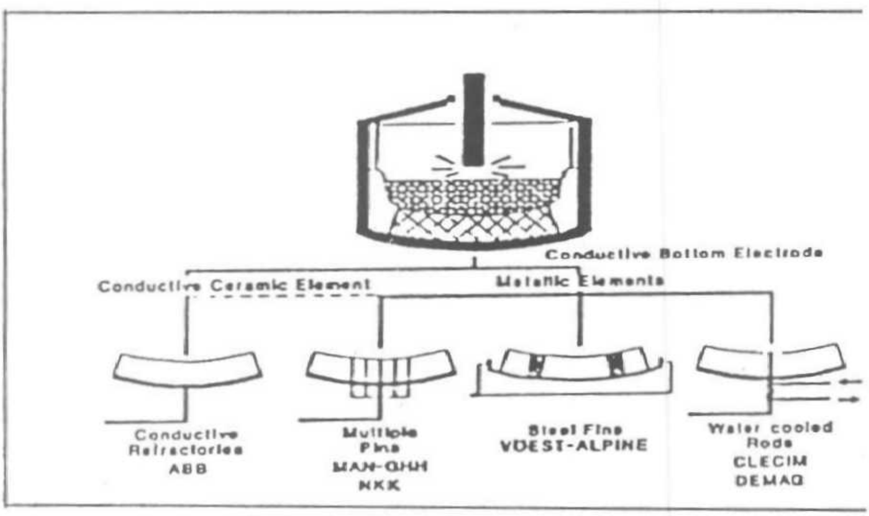

Fig.4 : Bottom design for DC-furnacess